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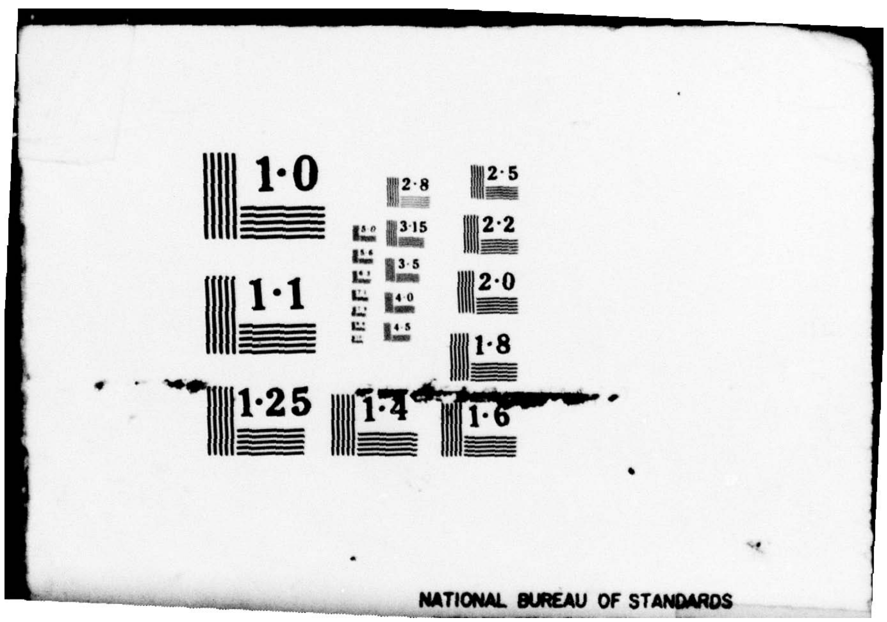
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by

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HORIZONTAL SHEAR SURFACE WAVES ON CORRUGATED SURFACES*

Indexing Terms: Sonic propagation, surface phenomena

Experiments have been performed on horizontal shear surface wave propagation along a corrugated surface. The results are in agreement with approximate theories used in analogous electromagnetic problems.

Introduction. A well-known problem in electromagnetism concerns the propagation of a TM-type surface wave along an infinite corrugated surface.[1-6] The insert in Fig. 1 illustrates this structure for the case of a substrate with finite thickness. In the electromagnetic case the shaded region represents an isotropic dielectric with electrical short circuit boundary conditions on the corrugated and bottom surfaces. The structure is uniform along the x direction.

This problem provides a good example of the generation of solutions to new acoustics problems by utilizing the analogy between Maxwell's Equations and the acoustic field equations.[7] In the electromagnetic problem considered here, the x component of the magnetic field satisfies the two-dimensional wave equation subject to boundary conditions requiring that the normal derivative of H_x be zero on all surfaces. The acoustic variable analogous to H_x is the x component of particle displacement velocity, which satisfies the ordinary wave equation in two-dimensional isotropic problems of the kind considered here. At traction-free boundaries parallel to the x-axis, the normal derivative of v_x is required to be zero. This shows that the

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electromagnetic problem has an exact acoustic analogue in which the insert of Fig. 1 represents a free isotropic elastic plate with a uniform grating of slots cut into the upper surface. The known electromagnetic surface wave solution is therefore directly applicable to this new problem.

The acoustic analogue solution generated in this way represents a new type of horizontal shear surface wave. Although most surface acoustic wave research has been concerned with Rayleigh waves, horizontally polarized surface waves are not unknown. Such waves exist on piezoelectric and magnetostrictive substrates, and also on layered isotropic substrates (Love waves). The waves considered here are unique in that they have a propagation velocity that is much slower than the bulk shear wave velocity and they also exhibit an <u>upper</u> cut-off frequency. These properties suggest potential applications in the areas of compact long delay lines and grating filters. It should be noted that these new surface waves require the presence of the corrugations and do not exist on a smooth surface, as Rayleigh surface waves do.

<u>Method of Solution</u>. Detailed treatments of the analysis are given in the electromagnetic references cited. Following Floquet's Theorem, one expands the field for $y < 0$ in terms of "spatial harmonics" $\exp(\beta_0 + 2\pi m/d)z$. Inside the teeth $(y > 0)$ the fields are expanded in terms of SH plate modes. Using an approximate method, we assume that only the dominant SH mode exists in the teeth and match the stress component T_{xy} on the plane $y = 0$ by Fourier analysis.[3,5] For the continuity condition on v_x at the same plane, either matching of the field at the midpoints of the slots[3] or

matching the complex power flow[5] is used. This leads to the dispersion relations

$$\frac{1}{kh\ \tanh kh} = \frac{\delta}{d} \sum_{n=-\infty}^{\infty} \frac{1}{\alpha_n h\ \tanh \alpha_n D} \left(\frac{\sin \beta_n\ \delta/2}{\beta_n\ \delta/2} \right)^{\mu}$$

$$\mu = \begin{cases} 1, & \text{midpoint matching} \\ 2, & \text{power flow matching} \end{cases}$$

$$\beta_n = \beta_0 + 2\pi n/d \ ; \ k = \omega/V_s \ ; \ \alpha_n^2 = \beta_n^2 - k^2 \ .$$

Over the range of parameters used experimentally we have found little difference between $\mu = 1$ and $\mu = 2$, and the second value was used. Figure 1 shows typical curves for a finite substrate thickness D, with the surface wave solution below the dashed diagonal and thickness modes for one value of D above the diagonal.

Results and Discussion. The dispersion curves were measured by observing in transmission the resonant frequencies of a section of corrugated surface with traction-free ends (Figs. 2 and 3). Fabrication of the grating resonators was accomplished by sawing 6 mil slots in aluminum plate. The measurements were performed using a frequency synthesizer and PZT-5A thickness shear input and output transducers affixed with Dow Resin 276-V9. The transducers were 0.034" thick and had a 1.00" horizontal aperture.

Surface wave resonances occur at frequencies where the grating is an integral number of half wavelengths long. In an N-slot grating this

means that

$$\beta_0 d = p\pi/N$$

where p is an integer. Measurements were made by observing the transmission resonances and counting back to zero to determine the mode index p. Results for various values of the parameters are plotted and compared with theoretical curves in Figs. 2 and 3. It is seen in Fig. 2 that the results are not sensitive to the lateral width of the grating. For the narrow grating rubber dampers were placed along the grating edges to suppress diffraction effects. The experimental points above the dashed diagonal correspond to the thickness modes shown in Fig. 1. These spurious responses create a problem in performing measurements near the surface wave cutoff frequency. Comparison of the $kd = \pi/2$ points in Figs. 2 and 3 shows that the deeper slots give a greatly increased amount of wave slowing. A higher order surface wave also appears in this case.

Because the polarization of the surface wave is shear horizontal, there is no scattering from the surface mode into the thickness modes at the traction-free end faces of the resonator, contrary to the case of Rayleigh surface wave reflections. However, the kind of transducer used does excite both types of modes. Although spurious mode excitation can be somewhat reduced by careful placement of the transducer and by damping the lower surface of the plate, mode interference remains a problem in frequency regions where the two mode types overlap. This is clearly shown in Fig. 3, where the accuracy of the measurements deteriorates at the higher frequencies, but this can be avoided by using a smaller value of D in order to increase the thickness mode frequencies.

The principle problems to be resolved in further study and exploitation of these waves are the development of suitable transducers and of techniques for fabricating narrow deep slots with smaller dimensions suitable for higher frequency operation. Interdigital transducers[8] and orientation dependent etching[9] are possible solutions to be examined.

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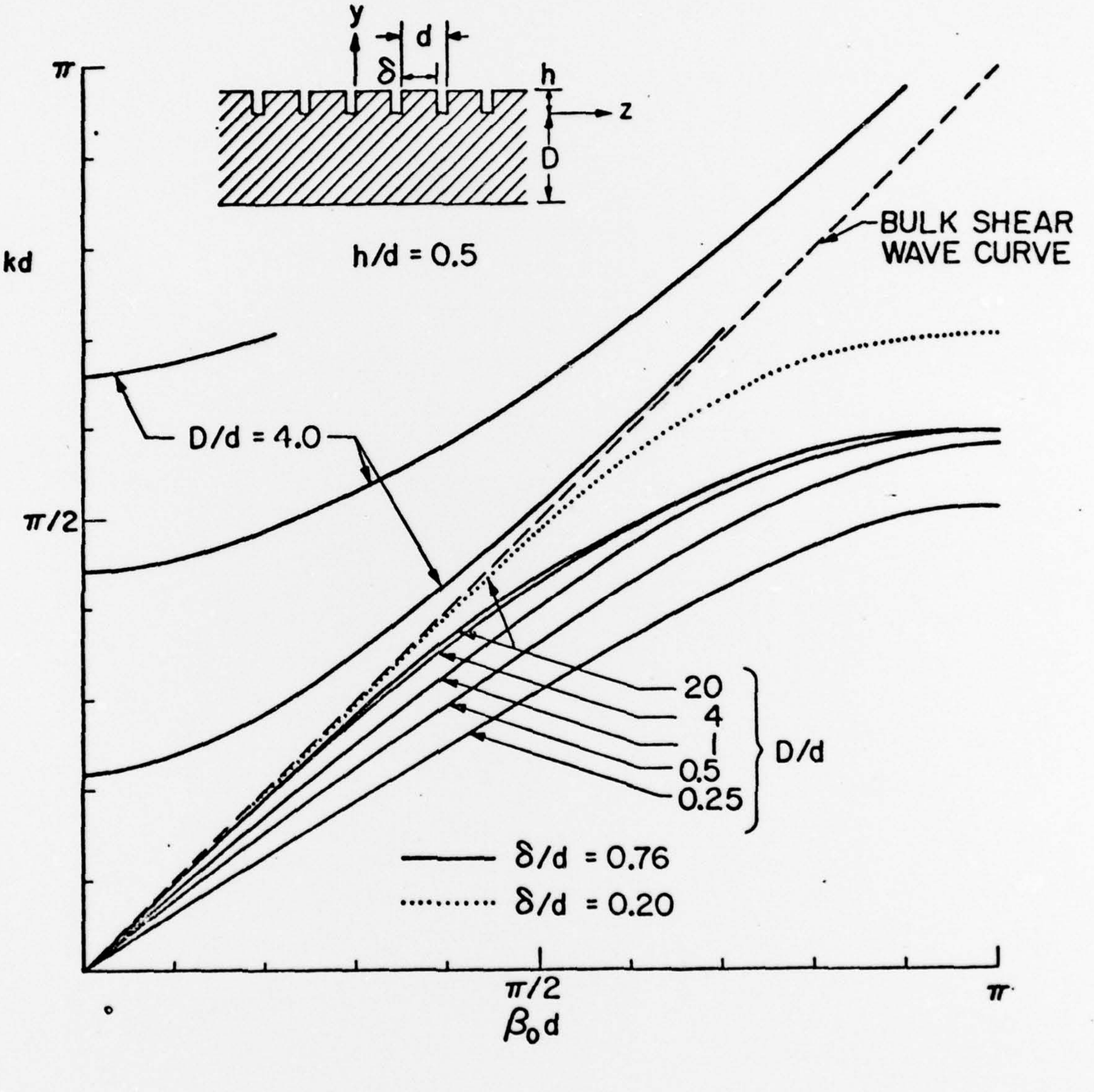
Figure Captions

1. Theoretical dispersion curves for horizontal shear wave propagation on a corrugated surface.
2. Comparison of theory and experiment for 6 mil x 12.5 mil slots. In the $N = 80$ case only a few of the observed resonant frequencies are shown.
3. Comparison of theory and experiment for 6 mil x 50 mil slots.



y
d
δ
h
z
D
h/d = 0.5
kd
π
π/2
BULK SHEAR
WAVE CURVE
D/d = 4.0
20
4
1
0.5
0.25
D/d
δ/d = 0.76
δ/d = 0.20
0
π/2
π
$\beta_0 d$

FIGURE 1

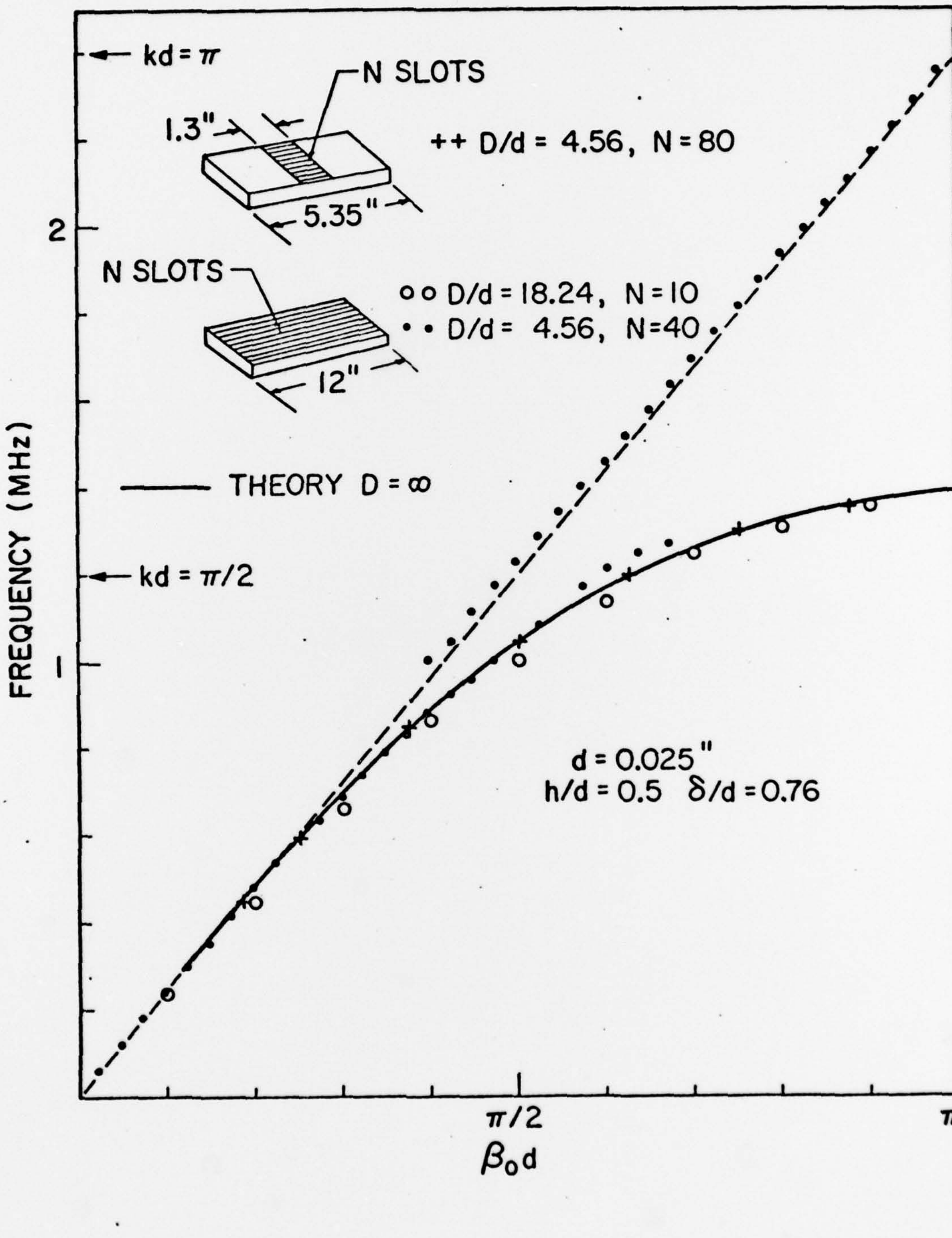

kd = π
N SLOTS
1.3"
5.35"
++ D/d = 4.56, N = 80
2
N SLOTS
oo D/d = 18.24, N = 10
•• D/d = 4.56, N = 40
12"
FREQUENCY (MHz)
THEORY D = ∞
kd = π/2
1
d = 0.025"
h/d = 0.5 δ/d = 0.76
π/2
π
$\beta_0 d$

FIGURE 2

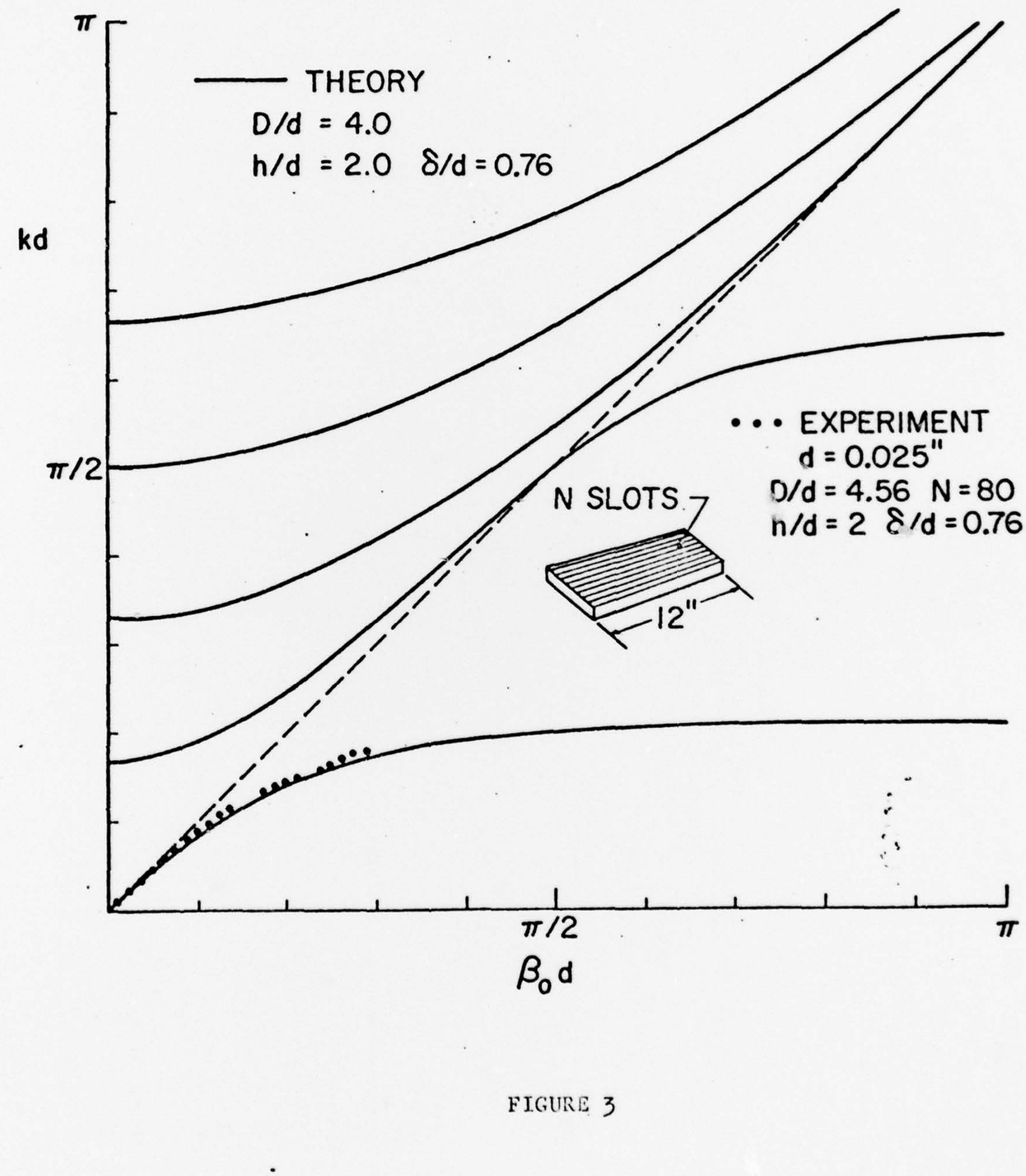

THEORY
D/d = 4.0
h/d = 2.0 δ/d = 0.76
kd
π
π/2
EXPERIMENT
d = 0.025"
D/d = 4.56 N = 80
h/d = 2 δ/d = 0.76
N SLOTS
12"
π/2
π
β₀d

FIGURE 3